Electronic Checklists on Multi-Purpose Displays:
A Better Way For Fighter Pilots to Manage Information and Situational Awareness during Periods of High Workload

A MONOGRAPH
BY
Patrick J. Doherty
Major USAF

MENS EST CLAVIS VICTORIAE

School of Advanced Military Studies
United States Army Command and General Staff College
Fort Leavenworth, Kansas

First Term AY 00-01

REPORT DOCUMENTATION PAGE

1. REPORT DATE (DD-MM-YYYY) 01-01-2001	2. REPORT TYPE monograph	3. DATES COVERED (FROM - TO) xx-xx-2000 to xx-xx-2001	
4. TITLE AND SUBTITLE Electronic Checklists on Multi-Purpose Displays: A Better Way For Fighter Pilots to Manage Information and Situational Awareness during Periods of High Workload Unclassified		**5a. CONTRACT NUMBER**	
		5b. GRANT NUMBER	
		5c. PROGRAM ELEMENT NUMBER	
6. AUTHOR(S) Doherty, Patrick J. ;		**5d. PROJECT NUMBER**	
		5e. TASK NUMBER	
		5f. WORK UNIT NUMBER	
7. PERFORMING ORGANIZATION NAME AND ADDRESS USA Command & General Staff College School of Advanced Military Studies 1 Reynolds Ave. Fort Leavenworth , KS 66027		**8. PERFORMING ORGANIZATION REPORT NUMBER**	
9. SPONSORING/MONITORING AGENCY NAME AND ADDRESS ,		**10. SPONSOR/MONITOR'S ACRONYM(S)**	
		11. SPONSOR/MONITOR'S REPORT NUMBER(S)	
12. DISTRIBUTION/AVAILABILITY STATEMENT A PUBLIC RELEASE			

,

13. SUPPLEMENTARY NOTES

14. ABSTRACT

After accumulating mishap data from the 1990's, accident investigations are revealing that pilot error causes approximately 80% of aviation mishaps. But, apply a bit more aggressive critical analysis into the type of human errors occurring highlight the fact that task saturation, lack of situational awareness, and checklist errors are the leading factors. Although ?stick and rudder? errors still occur due to poor piloting skills or deficiencies in training, the majority of the human errors are linked to the pilot?s mental abilities. Current USAF fighters are pushing the limit of the pilot?s ability to collect and comprehend enormous amounts of information. The cumulative effects of these technologies, which were intended to increase situational awareness and lethality, are in actuality responsible for the loss of situational awareness due to task saturation. The focus of this research will be on pilots? mental abilities and identifying known limitations within the cognitive process. But, innovative information technologies and other ergonomic efforts within the cockpit will also be looked at because it is impossible to look at the cognitive perspective in isolation. We must also look at the interaction the mind has with physical characteristics of a fighter aircraft. Renovating the vehicle in which the checklist information is communicated to pilots could be a potential solution to fight task saturation, susceptibility to spatial disorientation and overall mental errors in today?s cockpit. The fundamental conclusion resulting from this research is electronic checklists and data-based information banks can optimize pilot workload, situation awareness, and improve overall air combat performance by taking advantage of new information storage capabilities. The ultimate goal is to integrate this information into the ?glass cockpit? seamlessly without increasing pilot workload resulting in decreased pilot errors. Vital to the success of this endeavor is the ability to present this critical information in an intuitive and readily understood format. The advantages and effects gained by spending a minimal amount of money to add a simple word file to a multi-purpose display would be instrumental in helping to prevent aircraft mishaps, accidents, and deaths. Although this capability is not directly related to combat capabilities, implementation of an electronic checklist is an effective and efficient way to improve pilot performance and inevitably protect warriors and combat aircraft from preventable accidents. A force multiplier by any definition!

15. SUBJECT TERMS
accident investigations; cognitive process; aircraft accidents; ergonomics

16. SECURITY CLASSIFICATION OF:	17. LIMITATION OF ABSTRACT	18. NUMBER OF PAGES	19a. NAME OF RESPONSIBLE PERSON
	Same as Report (SAR)	57	Burgess, Ed burgesse@leavenworth.army.mil

a. REPORT Unclassified	b. ABSTRACT Unclassified	c. THIS PAGE Unclassified			19b. TELEPHONE NUMBER International Area Code
					Area Code Telephone Number 913 758-3171 **DSN** 585-3171

Abstract

Electronic Checklists on Multi-Purpose Displays: A Better Way For Fighter Pilots to Manage Information and Situational Awareness during Periods of High Workload by MAJ Patrick J. Doherty, USAF, 44 pages.

After accumulating mishap data from the 1990's, accident investigations are revealing that pilot error causes approximately 80% of aviation mishaps. But, apply a bit more aggressive critical analysis into the type of human errors occurring highlight the fact that task saturation, lack of situational awareness, and checklist errors are the leading factors. Although 'stick and rudder' errors still occur due to poor piloting skills or deficiencies in training, the majority of the human errors are linked to the pilot's mental abilities.

Current USAF fighters are pushing the limit of the pilot's ability to collect and comprehend enormous amounts of information. The cumulative effects of these technologies, which were intended to increase situational awareness and lethality, are in actuality responsible for the loss of situational awareness due to task saturation. The focus of this research will be on pilots' mental abilities and identifying known limitations within the cognitive process. But, innovative information technologies and other ergonomic efforts within the cockpit will also be looked at because it is impossible to look at the cognitive perspective in isolation. We must also look at the interaction the mind has with physical characteristics of a fighter aircraft. Renovating the vehicle in which the checklist information is communicated to pilots could be a potential solution to fight task saturation, susceptibility to spatial disorientation and overall mental errors in today's cockpit.

The fundamental conclusion resulting from this research is electronic checklists and data-based information banks can optimize pilot workload, situation awareness, and improve overall air combat performance by taking advantage of new information storage capabilities. The ultimate goal is to integrate this information into the "glass cockpit" seamlessly without increasing pilot workload resulting in decreased pilot errors. Vital to the success of this endeavor is the ability to present this critical information in an intuitive and readily understood format. The advantages and effects gained by spending a minimal amount of money to add a simple word file to a multi-purpose display would be instrumental in helping to prevent aircraft mishaps, accidents, and deaths. Although this capability is not directly related to combat capabilities, implementation of an electronic checklist is an effective and efficient way to improve pilot performance and inevitably protect warriors and combat aircraft from preventable accidents. A force multiplier by any definition!

Contents

Chapter I
Introduction

"Stinger 01 is number one, 4-ship radar trail, ready for takeoff", is the flight lead's transmission to the control tower as the four F-16 pilots have just finished their Before Takeoff Checklist. The mission is a 4-ship night surface attack sortie that entails the following: a night aerial refueling with a KC-10, a FLIR low level to the bombing range, four different bombing deliveries for a total of twelve bombs dropped, and a radar trail recovery back to home for a fullstop. The elastic straps of the g-suit are overflowing with mission related paperwork such as lineup cards, low level charts, offset updates, mission planning data in case manual input is required, and multiple attack cards. The required items on the checklist were completed without direct reference to the actual checklist. The cockpit is dark and cramped and the checklist is buried in the bottom of the pilot's helmet bag, which is jammed into the map case with the other required flying publications and aircrew aids. Stinger 04, a fledgling wingman, can't help but feel anxiety about the complexity of the mission at hand. The wingman, after an uneventful takeoff, successfully gets a radar lock on Stinger 03 before entering the weather and starts performing standard radar trail procedures. Passing 4000 feet on departure and fighting a persistent case of the "leans" from the clouds against the F-16's bubble canopy, red warning lights start flashing and "Bitching Betty" starts declaring the bad news. Stinger 04's mission just got more complex.

This scenario is not fiction. In fact, these types of situations are common place in training sorties within the United States Air Force fighter community. Real world conditions and the ergonomics of fighter cockpits encourage an overwhelming majority of the fighter pilots to store their checklists in the map case. Immediate access and the ability to retrieve the appropriate actions from the checklist during an emergency while maintaining aircraft control are the safety concerns to be addressed in this paper.

The scenario illustrates a pilot's responsibility to complete both normal and abnormal checklist procedures if the situation presents itself. Fighter pilots are trained to adapt to this constrained environment and execute normal checklist procedures with various techniques, compartmentalizing portions of the checklist by systematically scanning through the cockpit from left to right. These aviators are driven by a strong cultural belief that their mental capabilities will allow them to execute required procedures without referring to the actual checklist.

Abnormal checklist procedures vary depending on the type of fighter. Single engine fighters' checklists require pilots to recall boldface critical checklist procedures by memory without the assistance of the checklist. The demand for total recall of critical action items procedures during abnormal or emergency situations highlights the complexity and vulnerability to cockpit errors during high workload scenarios.

Just as Carl von Clauswitz explained the interactions of the "trinity" of warfare in his classic *On War*, aviation also possesses three distinct elements that possess a similar relationship. Aviation's trinity is the hardware and technology, training, and the pilot. Understanding the strengths and weaknesses of these three categories and balancing the relationships of each constitute the aviation community's pursuit to increase the performance of this remarkable system not yet 100 years old. A change in any one of these elements will affect the relationships and interactions with the rest of the trinity. Gone are the early days of flying when the preponderance of accidents was attributed to mechanical failures and faulty designs. As the aviation sector has matured, industry has reduced the number of accidents attributed to equipment failure with better engineering and quality control initiatives. The training of pilots continues to be an evolving process that is critical to safe flying operations. Initiatives to produce better performing pilots will continue to move aviation organizations forward until the human pilot is no longer needed to be a part of the equation. The third element of the trinity is the pilot, along with the physical and mental abilities of the human body and the brain. The pilot has become the weak link of the aviation trinity, providing the majority of causal factors contributing to aircraft accidents.

Recently, accident investigations are revealing that pilot error causes approximately 80% of aviation mishaps[1]. Pilot errors have statistically increased with the decrease in equipment failures due to better technology and training methods. But, apply a bit more aggressive critical analysis toward the type of human errors occurring will highlight the fact that task saturation and lack of situational awareness are the leading factors. Although 'stick and rudder' errors still occur due to poor piloting skills or deficiencies in training, the majority of the human errors are linked to the

pilot's mental abilities. These errors can be broken into the ability of the brain to; capture and prioritize critical information during dynamic situations, analyze the situation or problem correctly with the increased workload after the information is attained, and take appropriate action in a disciplined manner.

The relationship between innovative technology and pilot's mental abilities will be the focus of this paper. As highlighted above, today's USAF fighters are pushing the limit of the pilot's ability to collect and comprehend enormous amounts of information. Fighter pilots monitor safety of flight instrumentation just as air transport pilots accomplish their cross-checks. But, a fighter pilot's main mission is not just to get from point A to point B safely, but to kill people and break things. The requirements of warfighting adds an exponential amount of information for the pilot to monitor and manage inside and outside of the cockpit while employing his weapon system and executing effective survival tactics. The cumulative effects of these technologies, which were intended to increase situational awareness and lethality, are in actuality responsible for the loss of situational awareness due to task saturation.

The study of human factors and ergonomics are the pilots' tools needed to fight task saturation in this complex environment. Since the Wright brothers' first flight to current test pilots flying the F-22 Raptor, aviation and the pilot's checklist have become a vital and inseparable pair due to the inherent risks of flight. The job of the checklist is to provide critical knowledge and guidance to the pilot about the aircraft and appropriate actions to be accomplished. Safety reports continuously reveal a very delicate balance and integral relationship between a pilot and his checklist. Any pilot checklist deviations from the correct operating procedures will result in mishaps and fatal accidents.

Chapter II
Situational Awareness and Human Error

The focus of this paper is to better understand the connection between human errors and pilots' mental abilities. Further, what can the USAF provide to aircrew to help alleviate some of the pilot's vulnerabilities to complacency, task saturation, checklist error and omissions, and loss of situational awareness. To investigate this issue, situational awareness and human error need to be examined to lay the conceptual groundwork before further elements of this research can be discussed.

Situation awareness (SA) is defined as the perception of the elements in the environment within a volume of time and space, the comprehension of their meaning, and the projection of their status in the near future. It is a state of being or consciousness with varying levels of awareness to a particular event or situation. The definition highlights the importance of a pilot's ability to accumulate multiple sources of information simultaneously from his own aircraft, friendly aircraft communications, and the surrounding environment. Obviously, there are many variables that influence the quality of a pilot's SA to include; natural ability, training, experience, alertness, preconceptions, briefed objectives, and task workload. The definition highlights three distinct phases of SA which are perception, comprehension, and projection.

In this respect, it is easy to see when describing SA, one must assume there are different levels of SA. Level 1 SA, the lowest level of SA, is where a pilot simply perceives the cues surrounding him but does not have the time or capacity to get "ahead" of the jet or the situation. This level of SA confines the pilot into simply reacting to events or situations as they occur. Level 2 SA is achieved when pilots understand events due to knowledge and experience. This comprehension and ability to form patterns allows pilots to make the jump to the highest level of SA. Level 3 SA utilizes both previous levels to analyze and project the situation out into the near future. Pilots operating at this level are proactive, having efficiently prioritized and managed incoming sources of information while still owning a surplus of attentional and cognitive

resources to comprehend and project a particular situation. To operate at this third level, a pilot must understand the situation rather than just perceive the situation[2].

By attaining this level of awareness, or "big picture" of the situation, the pilot can project ahead of the jet for follow-on action. High situational awareness is acquired and maintained by knowing how and when to divide and focus attentional resources. In doing so, courses of action can be narrowed and chosen immediately with an insightful cost and benefits analysis. This idea emphasizes the importance that experience plays in the flying environment.

It is important to delineate the difference between a pilot's situational awareness, tactical performance, and his decision making skills. A pilot's mental model of the world around him and his place in it, his situational awareness, directs his decision making and tactical performance. A pilot's understanding or perception of a specific situation forms a critical input to, but is separable from, pilot decision making, which is the basis for all subsequent pilot actions[3]. To illustrate this difference, a person only needs to look at mishap reports. Even the best trained, most experienced pilots can make wrong decisions with incomplete or inaccurate situational awareness. This fact is no different for pilots in a fighter squadron.

Situational awareness is an outcome; a product that results from effective situational awareness management. The USAF emphasizes the importance of situational awareness and teaches its pilots techniques on how to gain and maintain it, as well as to recognize when situational awareness has been lost or degraded. When pilots detect a lack of awareness in a specific area, they can simply direct their attention to that issue through various techniques and regain awareness. This process is situational awareness management. The goal is to maximize the amount of time pilots possess Level 3 situational awareness, giving them an opportunity to make better decisions and have an increased safety margin.

Level 3 situational awareness will prepare and protect aircrew from surprises and uncertainty when encountering abnormal or emergency situations. Attention requirements increase significantly when subjected to high risk or high workload phases of flight. In the

complex environment of air-to-air and air-to-ground engagements, attention demands due to informational overload, complex decision making and multiple tasks can quickly exceed limited cognitive resource capacities. Problems with non-optimal information sampling, visual dominance, and channelized attention under high demands also seriously limit pilot situational awareness. The more prepared the pilot is to assimilate large amounts of information in a dynamic situation will, in all likelihood, result in better informed decisions[4].

Situational awareness is difficult to gain and maintain yet quite easy to lose with just a few seconds of misdirected or misprioritized attention. It is imperative that pilots are trained and equipped to manage situational awareness in all types of situations. More importantly, the USAF should identify the importance of situational awareness needs and prioritize efforts to solve this issue with all available technologies to assist pilots in the future.

Another perspective concerning pilot situational awareness can be thought of as an accurate perception of the factors and conditions that affect the aircraft and the formation, or the group of aircraft that are working together as a team. This individual view of reality is the result of a chain of information processing events that consists of sensing and decoding of environmental data. The pilot's brain classifies and attaches meaning to the data, making decisions and judgements based on the data, implementation of decisions, and monitoring feedback[5]. But, the real question of this perspective is whether there is such a thing as an accurate perception. Human factor researcher, Larry Bolman, suggests that because it is impossible for individuals to possess exact knowledge of the situation in their environment they must develop a "theory of the situation." This perceived theory forms from the individual's pre-existing knowledge database and past experiences. Acquiring the "truth" of a particular situation, with all of its complexities, is an unreachable goal. This aspect of the pilot's environmental assessment leaves the individual vulnerable to error, especially in complex and unfamiliar situations[6].

In an analysis attempting to categorize pilot error, critical incidents from over 1,400 pilots were investigated and four broad categories of error were identified. The error groups were attention, perception, decisional, and motor skills[7]. The first three categories are highly related to each other and they all speak to the very essence of situational awareness. Dr. Eleana Edens, in her philosophy dissertation, explains the connecting relationships between these cognitive activities.

> The finding from this study that pilot situational awareness is related to pilot attention/perception error was anticipated. Intuitively, the association between situational awareness and attention appears symbiotic. The concept of situational awareness embodies attentional processes. It is unlikely that adequate situational awareness will be attained and maintained without an appropriate attention level. Since, this study showed situational awareness is related to attention/perception and judgement/decision error and the analyses suggested that these errors are related, it should be noted that these three human activities appear to be closely integrated. These findings suggest that pilot environmental awareness level is related to the "quality" of subsequent judgements and decisions. Thus it has been empirically demonstrated that situational awareness does predict pilot cockpit error[8].

Automation, the replacing of human functioning with machine functioning, was theorized to help pilots make better assessments of their environment. Automation has achieved a number of goals to bring a higher quality of performance and efficiency to aviation. However, in the aerospace industry, every time a problem is solved by technology, and the cockpit becomes more complex, a new problem may be created[9]. New high-tech cockpits require pilots to possess the extra skills to monitor and set devices. But, it is within these two areas of monitoring and setting instrumentation that pilots are vulnerable to committing errors.

Justifiably, with the advancement of automation in the last 25 years and the complexity emerging with the man-machine interface, the study of human factors and human error have become very important and challenging endeavors. FAA accident analyses found that mishaps, which could be attributed to pilot error, share some common factors, each of which is an element of what has become known as the "resource problem." Cockpit Resource Management (CRM)

training was designed, in effect, to reduce the frequency of these factors. The FAA and NTSB identified the common factors as:

(1)   Preoccupation with Minor Mechanical Problems

(2)   Inadequate Leadership

(3)   Failure to Set Priorities

(4)   Inadequate Monitoring

(5)   Failure to Delagate Tasks and Assign Responsibilities

(6)   Failure to Utilize Available Data

(7)   Failure to Communicate Intent and Plans

Each of these factors are traps for losing situational awareness. It is thought that if pilots identify and manage these vulnerabilities, they will spend less time reacting with Level 1 SA[10]. Cognitive psychologists have led the way in trying to find effective methods of predicting and reducing dangerous errors by way of better understanding the human brain's mental processes. In doing so, their hope is identify and reduce situations vulnerable to error[11]. It is not the purpose of this discussion to fully expose all of the intricacies of human error, but to engage the reader in a dialogue that exposes the reader to generally accepted principles and themes within human error research.

The first concept to be acknowledged when addressing human error is the fact that intention must be accurately assessed before passing judgement on human error. Psychologist James Reason effectively describes the relationship between human error and intentional behavior through three questions regarding a given sequence of actions.

> *Were the actions directed by some prior intention?*
>
> *Did the actions proceed as planned?*
>
> *Did they achieve their desired end?*

> Notice that all of these questions are capable of being answered. In contrast to issues like basic motivation or detailed execution, the nature of the prior intentions, knowledge of whether or not the subsequent actions deviated from them and an appreciation of their success or failure are potentially available to consciousness[12].

…volition is fundamental and crucial to the psychological definition of human error. Thus, the term error can only be applied to intentional actions. It has no meaning in relation to nonintentional behavior because error types depend critically upon two kinds of failure: the failure actions to go as intended (slips and lapses) and the failure of intended actions to achieve their desired consequences (mistakes)[13].
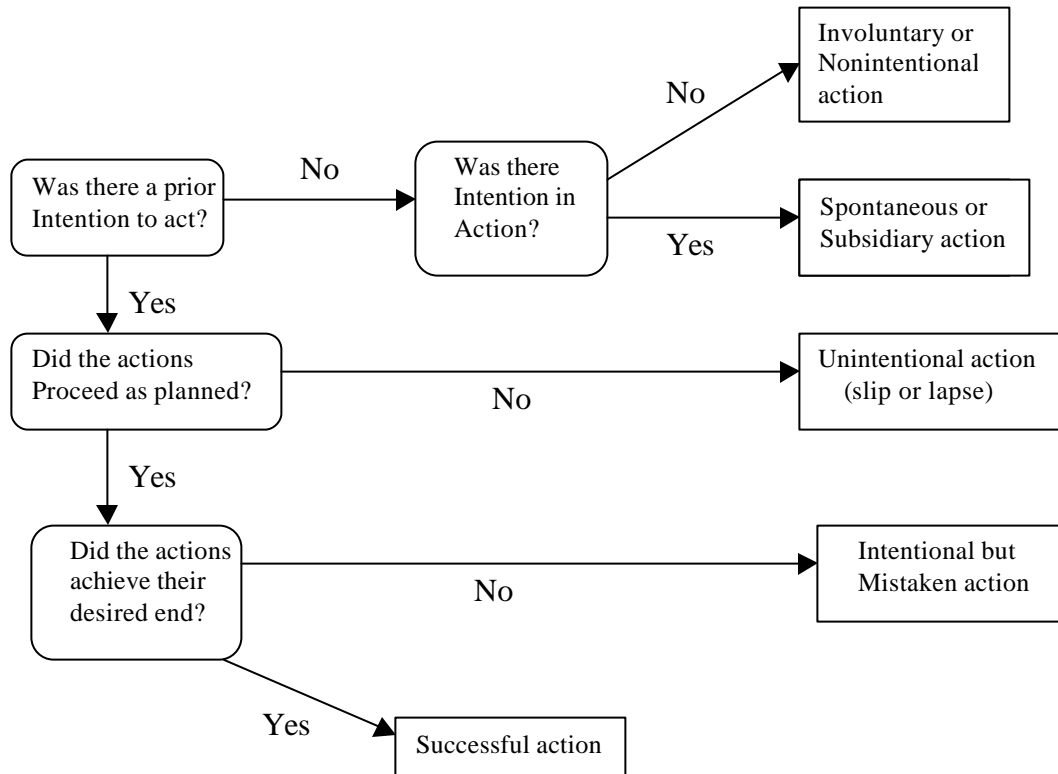
Figure 2.1. Algorithm for distinguishing the varieties of intentional behavior[14]

The next logical step in this discussion is to layout the psychological definitions of widely used human error terms. Error will encompass all those occasions in which a planned sequence of mental or physical activities fail to achieve its intended outcome, and when these failures cannot be attributed to the intervention of some chance agency. Slips and lapses are errors that result from some failure in the execution and/or storage stage of an action sequence, regardless of whether or not the plan that guided them was adequate to achieve its objective. Slips can be thought of as plans not executed correctly like a misspoken word. A lapse is

generally considered a failure of memory. Mistakes are deficiencies or failures in judgmental and/or inferential processes involved in the selection of an objective or in the specification of the means to achieve the objective. Another way of distinguishing these two basic error forms is as planning failures (mistakes) and execution failures (slips and lapses)[15].

As a group, cognitive psychologists are challenged to agree on a known set of determinants that yield human error. That being said, Dr. Reason classified errors under general principles in an attempt to add structure to the problem. He distinguishes the errors into three different levels; behavioral, contextual, and conceptual. He offers a simpler way and breaks them down to the "What?", "Where?", and "How?" questions about human errors. The behavioral level of human error is the most recognizable to the casual observer. General characteristics of this grouping are errors of omission-commission, repetition, and sequence. The consequences of these actions or inaction usually result in damage or injury[16].

The contextual level classification attempts to answer questions of error in regard to what was the exact situation at the time and location of the error. This perspective focuses on the environment that surrounded the individual error; trying to distinguish certain trends in human errors defined by specific situations or tasks[17].

Lastly, the conceptual level of error classification attempts to theorize about causal factors. As the name implies, this level is less concerned about the error's observable facts or specific information about the environment at the time of the incident[18]. The conceptual level is particularly interested in institutional perspectives to certain problems to include; training, assumptions, and organizational culture. A systems approach to identifying how an error occurred is a fair analogy.

As was pointed out earlier, when discussing error and intent, it can be assumed that errors originate between the thought of an action and the action itself. By defining performance levels or stages will help distinguish and identify error types. The cognitive stages of intentional

consciousness are planning, storage, and execution. Thus, the previously defined errors can be categorized in relation to these stages.

Cognitive Stage	Primary Error Type
Planning	Mistakes
Storage	Lapses
Execution	Slips

Table 2.1. Classifying the primary error types according to cognitive stage occurrence.

Mistakes can be further subdivided under levels of experience, which plays a critical role in the pilot's ability to process information and execute without error. The first is failure of expertise, where some pre-established plan or solution is applied inappropriately. The second reason for mistakes is a lack of expertise, where the pilot, not having an appropriate "off the shelf" routine, is forced to work out a plan of action from acquired basic principles and whatever knowledge the pilot possesses[19].

Error forms, on the other hand, are prevalent at all levels of cognitive activity. There are two primary factors that shape error forms: similarity and frequency. The origins of these two errors are found in the human brain's automatic retrieval processes of similarity-matching and frequency-gambling, by which knowledge structures are located and delivered to consciousness. Experience provides an overarching input into the information process and directly affects information retrieval. Experience gives pilots similarity and frequency information when confronted with a specific problem or event as the pilot is assessing the situation. The pilot matches the contextual elements of a previous situation with the current and executes a successfully proven course of action. Otherwise, the pilot is unable to find similar contextual elements and resorts to the most frequent course of action that has yielded successful results in the past[20]. Similarly, the predicament of an inexperienced pilot, as is the case in the opening scenario, results in the young pilot unable to draw from a wealth of experiences to select an appropriate or acceptable course of action.

11

Aircraft designers and Air Force leaders need to be aware of fighter pilot's higher level situational awareness needs and vulnerabilities to human error within this dynamic, complex system. In doing so, they will initiate a more thorough systems analyses to helping pilots solve the information proliferation problem which is currently engulfing them.

Chapter III
Information Processing

Aircraft have evolved from the simple to the complex. Today's fighter aircraft are pushing the limit of the relationship between man and machine and human factors science has been investigating this unique relationship to understand it more fully. Information processing directly affects and is particularly interested in how humans interact with systems such as aircraft, ships, and computer themselves. A principal feature of information processing is the assumption of a series of stages or mental operations that occur between stimuli and responses. Figure 3.1 shows a typical four-stage information processing model[21].
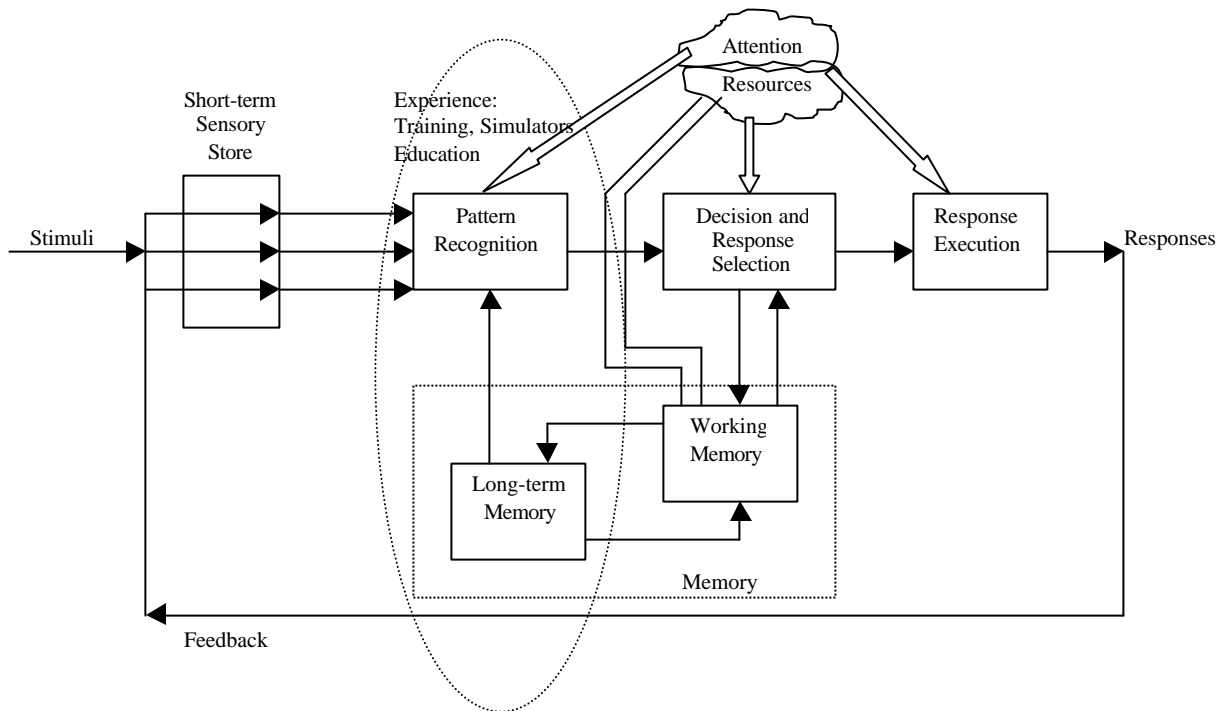

Figure 3.1   A model of information processing

Today's pilots process enormous amounts of information while flying at blinding speeds at extremely low altitudes in high threat environments. The information process is critical in this environment and a split-second decision or reaction can mean life or death. Understanding the

information process is a very crucial part of the man-machine interface. The model in Figure 1 is an example of what a pilot would process during a landing.

The first stage is the short-term sensory store in which information is represented in the sensory store in terms of physical features. The text on this page is represented in the visual sensory store as a pattern of dark shapes against a white background. This visual display lasts only briefly (less than 1 second for visual sensory store) and does not require attention resources[22]. The same would be for a pilot to visually see the runway. The pilot does not need to allocate any special attention or thought process toward visually acquiring the runway, but the snapshot of the runway is absorbed internally in the pilot's mind.

The second stage, pattern recognition, is the most important of all the stages. It is at this stage that the physical stimulation in the sensory stores is integrated into meaningful elements. This stage recognizes the black print on this page as words and adds true understanding and meaning to the text. This pattern recognition process involves mapping the physical codes of the sensory store into meaningful codes from memory. The ability of the brain to apply attention resources to this process will decide how efficient the mind recognizes patterns and extracts applicable experiences from long-term memory. As seen in Figure 3.1, the author includes experience as an added category that encompasses pattern recognition and long-term memory. The cognitive psychology community, as a whole, is becoming more interested in how experienced people make life-and-death decisions in an astonishingly short of time. A growing number of researchers have moved out of the laboratory, to work in the area of naturalistic decision making—that is, the study of how people use their experience to make decisions in field settings[23]. The dynamics that interact within this stage of the information process are extraordinary and are trying to be understood by professionals in this field. One of these experts is Gary Klein, author of *Sources of Power*, and he shares some insights into the dynamics and complexity of this stage in the following passage from that book.

We have found that people draw on a large set of abilities that are sources of power. The conventional sources of power include deductive logical thinking, analysis of probabilities, and statistical methods. Yet the sources of power that are needed in natural settings are usually not analytical at all—the power of intuition, mental simulation, metaphor, and storytelling. The power of intuition enables us to size up a situation quickly. The power of mental simulation lets us imagine how a course of action might be carried out. The power of metaphor lets us draw on our experience by suggesting parallels between the current situation and something else we have come across. The power of storytelling helps us consolidate our experiences to make them available in the future, either to ourselves or to others. These areas have not been well studied by decision researchers.[24]

Mr. Klein's naturalistic decision making studies focused on groups of professionals including firefighters, pilots, nurses, military leaders, nuclear power plant operators, and chess masters to name a few. The common thread that ran through these different professions was their everyday requirements to excel in situations driven by time pressure, high stakes, inadequate information, unclear goals, cue learning, and dynamic conditions. The four sources of power outlined in the passage above compliment the pattern recognition stage of the information processing model in Figure 3.1. Intuition, mental simulation, metaphor, and storytelling are the pillars of experience that embrace Klein's recognition-primed decision making model (RPD)[25].

By using the examples of a pilot trying to time the execution of a flare during a landing and the young pilot's situation described in the vignette, it can be seen that experience plays an important role in how pilots process information and make decisions. Pilots' experiences are continuously gathered through training sorties, emergency procedure simulators, and education-based currency requirements. Mr Klein's research shows that these experiences provide pilots with a basic set of patterns, which can be matched with the current situation and an appropriate response is executed in a timely manner using the RPD model.

Intuition is a source of an individual's ability to recognize situations from experiences and know how to react to them. Intuition, defined as recognizing things without knowing how the recognition is attained, is always discussed, taught, and emphasized in flying squadrons. It is usually presented as a pilot's warning tool of an impending dangerous situation and is described

when a pilot's "hair on the back of his neck stands up". Intuition will allow the situation to be understood immediately and give pilots focused goals, expectations, and appropriate responses. There is a direct correlation between experience and intuition. The more flying time a pilot possesses will undoubtedly increase his amount of intuition that he possesses. Experienced individuals can cut through a complex situation and focus on the relevant cues and discard the distracting ones because of their superior situational awareness[26].

The third source of power mentioned by Klein's passage is metaphors and analogues. Both of these processes can assist in helping to understand situations, generate predictions, solve problems, predict events and make plans. Both metaphor and analogues communicate interactions and lessons that influence thought patterns regarding a certain subject by providing virtual experiences. Decision makers will frame situation awareness by identifying critical information and desired endstates that relate to the scenario[27].

The fourth power that can be a useful technique during the pattern recognition stage is story telling. Klein proposes humans are naturally inclined to see and organize their world into a set of patterns to more easily understand their surroundings. Likewise, they like to organize the cognitive world--the world of ideas, concepts, objects, and relationships. Stories are used as an organization tool to facilitate this need to align patterns and help provide meaning to the subject[28]. Seeing that experience is a valuable commodity throughout this discussion so far, pilots use stories at the end of the day as a technique to share and communicate unique experiences, solutions, and pitfalls to pilots young and old. Again, these stories can provide the brain with important solutions and patterns that can be called upon if needed even if the individual did not actually experience the story himself.

Memory plays a critical role in the information process and is the subsystem that must retain information and data before it is translated to physical/motor skills. Human factors identify two different types of memory; long-term and working. Long-term memory is divided into two identifiable groups. Semantic memory represents memory for meaning. The definition of a

word, mechanics of riding a bike, or flying a plane would be considered semantic memories. Design engineers are very aware of this relationship and concentrate on the interface between humans and knowledge-based information systems. The goal is to put information in the cockpit in a package that the pilot can use most efficiently. The other sub-group of long-term memory group is episodic memory, representing knowledge about specific events. An example of episodic memory would be a pilot's memory of a recent flight. The study of episodic memory is important for accident and critical event investigations[29]. The ability of the mind to store knowledge and organize it in memory has its limits and is a very important concept.

Short-term, or working memory, is the system that the pilot uses when something is heard or seen that requires a response directly related to what was just heard or saw. A pilot's capacity to process information is closely related to the human working memory. There are two types of working memory, verbal and visual code memory[30]. An example of verbal code memory is a pilot hearing an air traffic controller giving instructions and then the pilot following the instructions with the airplane. An example of visual code memory is when the pilot must recall the relative position of his aircraft off the airfield after a quick look outside the cockpit. Regardless of the type of code, the capacity of working memory is quite limited, and its demands on the pilot's limited attention resources are high. It is this very limitation that should be of concern to both the designer and user of aviation systems[31].

The minds working memory is only capable of recalling 5 to 9 unrelated items under ideal situations such as when full attention can be secured. Lists that exceed this limit are likely to have one or more items forgotten or transposed before recall takes place. This limitation is a very important concept that must be understood when voice messages are relayed with too much information or computer menus or procedures manuals that have too many options for the working memory to digest. The "magic number 7 ± 2" becomes a very important theory when discussing the issues pertaining to the ability of the pilot to recall items in a complicated emergency procedure[32].

Other experts in the human factors community have defined this interaction between pattern recognition and memory as schema. Schema are memory stores which organize bodies of knowledge into integrated meaningful frameworks. Schema can provide coherent frameworks of understanding, encompassing highly complex system components, states, and functioning. Studies have also shown that schema will be used to make judgements concerning which information is relevant to a problem. Further study in this area has found people will categorize information almost immediately into a schema that directs problem solving[33]. This mapping is very complex and the perceptual processes are often limited by the availability of attention resources[34]. An example would be an inexperienced pilot becoming so focused and overwhelmed with the dynamics of the landing phase that the pilot fails to "hear" radio transmissions directed toward him. There is no hearing loss but the inability of the pilot to allocate attention resources to recognize the pattern of the radio transmission. This is one of the first signs instructor pilots perceive when their students start losing situational awareness.

The next stage is the decision and response selection stage. At this stage, a stimulus has been recognized and a decision must be made as to what to do with that particular information. The information can be stored for use at some other time, or it can be integrated with other available information, or it may initiate a response. Each of the options will be weighed for potential costs and benefits and a decision will be chosen.

Klein's second source of power that decision makers wield mentioned in the passage is mental simulation and corresponds quite well with this stage. Klein defines this power as the ability to imagine people, objects, and events consciously and to transform those people, objects, and events through several transitions and finally picturing them in a different way than at the start. This technique can be used to explain the current state of events by mentally simulating past events and transitioning them to the present to help them explain the dynamics involved in the current situation. Likewise, mental simulation is a very useful tool for decision makers to project into the future. These simulations help the brain to make sense of external cues and

information, facilitating the interpretation of a situation and diagnosing the problem. This process compliments the concept of situation awareness and helps form and verify an individual's situational awareness while evaluating a response to a given stimulus. "Seeing" this picture allow decision makers to prepare for the future or to troubleshoot a possible course of action and avoid possible pitfalls that would otherwise be omitted[35].

Mental simulation is different from intuition, and does not simply mean recognizing situations and projecting them forward. It is used when not all of the variables of a situation are known. The simulation attempts to explain the sequence of events and expose the unknowns along with solutions to eradicate the problem. Again, experience is a requirement to produce useful mental simulations. Another limitation is mental simulations are limited to scenarios possessing a finite set of variables and complexity. The brain's working memory is only able to simulate a few sets of concurrent interactions and extrapolate them out to a meaningful conclusion with clarity[36].

If the decision is made to make a motor response, such as making a flare for a landing, the last stage of the information processing model called response execution translates this decision into a coordinated sequence of motor commands. If the jet flared too high, the whole process starts over again with the help of the feedback loop telling the pilot of the high flare by using the sensory stores and inputting this new data into the pattern recognition phase. Klein's research started showing a trend that decision makers were not comparing two or more options in a process or comparative evaluation. It was not that commanders or decision makers were refusing to compare options; rather, they did not have to compare options. The decision makers could come up with a good course of action from the start. Even faced with complex situations, these experienced leaders could identify similarities from past experiences and instantly know how to react. Their experience let them identify a reasonable reaction as the first option they considered, so they did not bother thinking of other options.[37]

The stimuli-response theory and the information processing model are very simple and important concepts that must be understood and integrated into the equation when dealing with human factors-related discussions and problems.

Chapter IV
Cockpit Automation and Workload Management

Past aircraft designs fulfilled specified mission requirements or roles based upon available technology. Specific roles such as reconnaissance, air-to-air, and air-to-ground had specific aircraft designed for that role. The information age exploded onto the scene and technology offered the military aviation community a greater flexibility of missions and increased capabilities. However, the price tags on these new war machines are staggering. Today's advanced aircraft are extremely expensive because of the latest technology put into their designs. Due to the budget constraints of the last two decades the Department of Defense sought modern fighters designed to handle multiple missions to make up for the smaller number of aircraft in the inventory. For very practical reasons, all modern air forces have turned to multi-role tactical aircraft[38]. The ability of one airframe design fulfilling several mission requirements is only limited by the pilot's ability to understand his situation and draw upon his experiences and information inside the cockpit to successfully achieve mission objectives. The ability of the pilots to maintain proficiency in the multi-role fighter is very tasking. Workload levels are extremely high and it is extremely difficult to maintain the needed skills for each individual mission required for combat.

Our society has welcomed the conveniences of automation and is demanding technology accept an even greater role in duties and responsibilities of everyday life. The aviation community has struggled to address and correct the human dimension of accidents with technology and automation. For a number of reasons, automation has been the solution to this problem with some very attractive side benefits. One reason is humans, especially western civilizations, thrive on the concept of control. The definition of control given by James R. Beniger in his book, The Control Revolution, is the purposive influence toward a predetermined goal. Control encompasses the entire range from absolute control to the weakest and most probabilistic form, that is, any purposive influence on behavior[39]. It doesn't matter what kind of

control. Since the dawn of mankind, humans have sought out control of the environment, animals, fellow humans, and anything else that is within our influence. Automation is one of the most straightforward expressions of control. Mr. Beniger lays out the foundations of control in the following paragraph:

> Inseparable from the concept of control are the twin activities of information processing and reciprocal communication, complementary factors in any form of control. Information processing is essential to all purposive activity, which is by definition goal directed and must therefore involve the continual comparison of current states to future goals, a basic problem of information processing. Simultaneously with the comparison of inputs to goals, two-way interaction between controller and controlled must also occur, not only to communicate back the results of this action (hence the term, feedback)[40].

Again, the recurring themes of situational awareness and the information processing are subtle and conceptually connected with human performance and control. Earl Wiener identified several other more practical reasons for cockpit automation[41]:

(1)   Availability of technology
(2)   Safety
(3)   Economy, reliability, and maintenance
(4)   Workload reduction and certification of two-pilot transport aircraft
(5)   More precise flight maneuvers and navigation
(6)   Display flexibility
(7)   Economy of cockpit space
(8)   Special requirements of military missions

The last three reasons are discussed in the next chapter. It was a common perception that pilots would benefit from technological advances with simpler tasks and a reduction in workloads. Therefore, a reduction of human errors would be the outcome and overall safety enhanced. But, a large number of pilots surveyed admitted that while they enjoyed flying highly-automated aircraft, they had strong doubts about safety and workload reduction.   Their reservations about safety were based on a fear that pilots tended to lose situational awareness in the automated cockpit and that merely monitoring the new instrumentation would lead to complacency[42]. Although complacency and boredom can be the products of cockpit automation, the perceived loss of control to automation can cause pilots to become psychologically uncomfortable and experience higher levels of stress[43].

As this dynamic between man and machine has evolved, a new threat has emerged: A tendency for the man in the loop to dismiss, or not understand, his responsibilities in regards to managing and controlling the machines he presides over. These complex systems have shown a vulnerability to invite large blunders with terrible consequences[44]. Now, the nature and scale of potentially hazardous technologies, especially nuclear power plants, means human errors can have adverse effects upon whole continents over several generations. A Ph.D. in psychology and industrial engineering and past president of the Human Factors Society has extensively researched aspects of automation's interaction with human vigilance, automobile and aviation safety. Dr. Weiner sums up the pros and cons of automation in Table 4.1.

Advantages	**Disadvantages**
Increased capacity and productivity	Dehumanizing, lower job satisfaction
Reduce manual workload/fatigue	Low alertness of human operators
Relief from routine operations	Systems are vulnerable to large errors
Relief from small errors	Silent Failures
Operations more precise	Manual flying proficiency low
Economically efficient	Over-reliance, complacency
	False Alarms
	Automation-induced failures
	Increase in mental workload

Table 4.1. Advantages and Disadvantages of the Highly-Automated Airplane[45]

Wiener also highlights other possible detrimental effects of automation on pilots. He explained that decreasing control and increased monitoring, pilots are prone to become bored during certain phases of flight. This can lead to two insidious and dangerous results: taking more time to detect failures or errors, and becoming less accurate in diagnosing these failures and errors. There is also evidence that pilots occasionally fail to respond appropriately to an emergency.

High performance military aircraft present a complex and dynamic environment to its pilots and aircrew. Advancements in technology have seen the implementation of computerized/automated technologies in aircraft that has actually decreased the physical workload required to fly the aircraft. The hypothetical decrease in workload allows the pilot

more time to accomplish additional duties required by the addition of the "glass cockpit's" new technologies. The pilot can direct his attention resources to onboard sensors and does not have to concentrate entirely on flying the aircraft, as pilots of past fighter aircraft did. Pilots can now go "hands off" to take care of targeting, sensor cueing, employing ordnance, threat awareness, and other cockpit duties. However, the pilot is still responsible for the safe operation of the aircraft, and this introduces monitoring requirements that increase mental workloads. The problem is human beings, in general, are inefficient at passive monitoring. Humans get bored. Their minds naturally move on to more engaging thoughts. That is when critical details are likely to be missed. When confronted with an abnormal situation during their daydreaming, they are required to initiate problem solving from a cold and distracted start[46]. The arrival of these new types of cognitive errors in the aviation community and other technological fields galvanized the human factors community to search for solutions.

Human factors research has demonstrated that the workload of an aircrew or pilot is a very important determinant in causing human error[47]. Pilot performance, under most circumstances, is most reliable under moderate levels of workload and stress that do not change suddenly and unpredictably. High levels of workload and stress are obviously going to increase the likelihood of pilot error. Excessive workload errors arise from the inability of the pilot to cope with high information rates imposed by the environment. The other extreme happens when workload or stress is too low and boredom sets in and the pilot is lulled into not properly attending to the task at hand[48]. Everyone operates most effectively somewhere between these two extremes at some moderate level of stress. The relationship between stress and performance has been repeatedly proven and verified[49]. At very low levels of stress or workload, motivation and attention are minimal and results in poor performance. On the other end of the spectrum, at very high levels of stress and workload, panic and task saturation set in and performance deteriorates dramatically. A visual representation will enforce this idea in Figure 4.2.
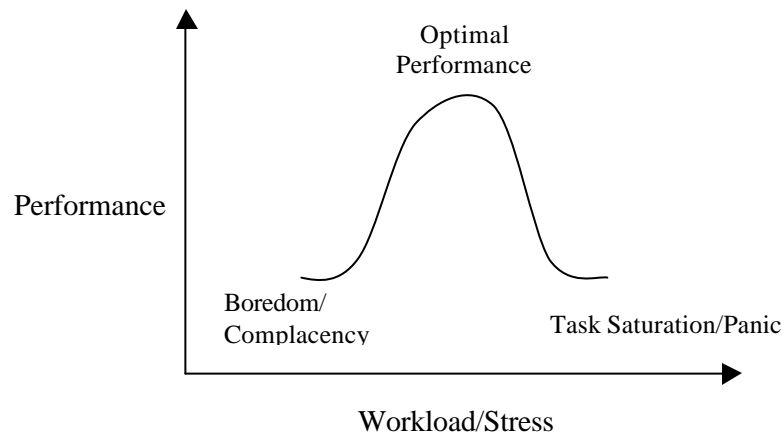
Figure 4.2. Relationship between Workload/Stress and Performance[50]

Human engineering experts must continuously balance automation versus human control, trying to achieve acceptable human performance levels.

The factors found to have an influence on mental workload are; task distribution, memory, and unexpected events[51]. Distribution of flight duties is probably one of the most important factors influencing workload. Commercial aviation cockpit resource management programs spend a lot of time and resources addressing task distribution. It is no secret that workloads and stress will be higher during abnormal or emergency situations than any other phases of flight. Cockpit resource management techniques encourage a delineation of tasks between pilot and co-pilot, preventing a single crew member from becoming task saturated. The goal is to keep all of the crew operating in that optimal performance zone and increase the overall rates of success significantly. The USAF understands the benefits of task distribution and has encouraged instituting techniques that parallel multi-crew task distribution techniques. In the case of an aircraft experiencing an emergency within a 4-ship formation, the other jets would assist the emergency aircraft with mutually supporting tasks such as; clearing traffic, radio communications, checklist assistance, battle damage checks, navigation, and providing an overall game plan if needed. In practice, these techniques of providing mutual support are proven solutions to tough problems in the past. But, all of these techniques rely on certain environmental

25

requirements that are conducive to assisting wingmen in trouble. Clear radio communications and clear daytime skies help immensely. What if the situation is similar to the opening scenario? Depending on the situation, the pilot experiencing the emergency can become isolated from assisting wingmen and controlling agencies, requiring to rely on his own awareness, knowledge, and skills to solve the problem. Task distribution techniques are not options in these cases.

The second factor, is the role of memory and how it relates to mental workload and information processing. In short-term memory, or working memory, the human brain can remember a limited number of items. These items are stored by rehearsing them until they are no longer needed or until they have been transferred into permanent storage, or long-term memory[52]. Once information is located within long-term memory, they don't need to be rehearsed to be remembered, but do need to be accessed using the correct "retrieval cues"[53]. The measurement of mental workloads and memory recall is a very complex and challenging task. In a recent study measuring memory performance of military pilots in flight simulators, working memory versions of a specific flight profile outperformed long-term memory flight profiles. Multiple studies have shown similar trends in memory performance[54]. Analyzing this data exposes a vulnerability to poor performance and pilot errors due to long-term memory recall.

The aviation community has three possible solutions to the mental workload-memory problem. Human engineers can design systems that take advantage of short-term memory performance during high mental workload phases of flight. Secondly, ergonomists can capitalize on automation's characteristics and advantages by enabling automation a bigger role in aviation by accepting responsibility for heavily memory-dependent tasks and assigning them to onboard computers. Lastly, a design approach incorporating advantages of both techniques can be sought after, enabling a well thought out systems approach to reducing fighter pilots' total workload.

The last factor influencing mental workload is unexpected events, which play critical roles in causing workload and stress levels to reach unmanageable levels. Unexpected events disrupt the normal execution of a flight "script" and cause pilots to work outside of their normal patterns,

becoming vulnerable to task saturation and human error. They are asked to provide a solution in such scenarios, regardless of whether the pilot is familiar with the complexities of the situation. Unexpected events can be divided into two separate groups: abnormal, and emergency. Abnormal events are characterized by intrusions of the normal routine. These events require a large amount of mental workload to provide quality decision making in a timely manner. Examples of abnormal events would include; poor weather conditions along route of flight, Air Traffic Controller (ATC) requests for spacing and separation, aviation companies perceived pressure to maximize profits, and wingmen requiring assistance. Although emergencies are abnormal, they differ from abnormal events because of the seriousness at which they are viewed and are closely tied to the inherent dangers of flying. Examples of emergencies include questions of aircraft structural integrity, engine or other major system malfunctions, collisions, low fuel status, availability of a suitable airfield, and any other event reducing the likelihood of returning safely. A recent article in *Flying Safety* discussed interruptions and distractions and the relationship that is created with attentional resources when pilots are exposed to non-routine situations.

> Ironically, it seems one of the biggest hazards of "abnormals" is becoming distracted from other cockpit duties. Abnormals easily preempt crews' attention for several reasons. Recognizing the cockpit warning indicators, identifying the nature of the problem, and choosing the correct procedure require considerable attention. Crews have much less opportunity to practice abnormal procedures than normal procedures, so choosing and running the appropriate checklists require more effort and greater concentration of mental resources than running normal checklists. Also, in situations perceived to be urgent or threatening, the normal human response is to narrow the focus of attention, which unfortunately tends to diminish mental flexibility and reduce ability to analyze and resolve non-routine situations[55].

Recently, two researchers attempted to quantify pilot performance by studying nine professional pilots in three separate simulator situations to include; normal, abnormal, and emergencies. Johannsen and Rouse's objective analysis found that emergency scenarios were associated with the highest workload levels and the greatest number of performance errors, while the abnormal flights resulted in higher cognitive activity than normal flights required[56]. This

research was directed at the civilian aviation community, as are the majority of human factors studies. There are a number of reasons for this to include; lack of civilians ability to research military databases, easy access to civilian databases, and military's priority toward weapon systems. But, the results of this research can be extended to the military. In fact, the questions and results of workload management and human performance studies are more germane to combat aircraft. Military aircraft designers and Air Force human factors engineers need be acutely aware of pilot mental workload versus automation relationship when adding new technologies to the cockpit. Acquiring new weapon systems with a pilot-centric systems analysis will help turn and reverse the emerging mental workload problem in today's fighter cockpits.

Chapter V
Human Factors and the Electronic Checklist

With the emergence of technology and automation, the world has become increasingly complex and America has become more dependent on the man-machine relationships to fill everyday tasks. However, in the last two decades, it has become readily apparent that a new type of human error has surfaced in aviation. The FAA and NTSB appointed a commission to investigate the increase in serious aviation accidents that were resulting in deaths, jeopardizing the confidence of air transportation safety. Thus, the newly empowered study of human factors, or ergonomics as described in Europe, was thrust on to the scene to find solutions.

Human factors is defined as the technology concerned to optimize the relationships between people and their activities by the systematic application of the human sciences, integrated within the framework of system engineering[57]. This technical definition needs further explanation to understand the essence of human factors. Technology, in this sense, is defined as the tools, skills, and professional beliefs to solve real world man-machine interface problems in a practical nature. This general definition shows the emergence of the term "ergo" in our society extending beyond the workplace and entering all types of activities and environments to include the home, public buildings, furniture, automobiles, schools, and leisure activities. Human sciences comprise those studies covering structures and nature of human beings, their capabilities and limitations, and their behavior[58]. More simply put, human factors researches fitting the machine to human limitations. The study of the man-machine relationship is done in the "field" with close interaction with the actual system operators, soliciting their insights and needs. Once human factors scientists are armed with this critical information, they can make effective inputs into the design and operation of each system. The new automation technologies put into the cockpit cannot be looked at as a series of individual systems stuffed into the jet just to add capabilities to the aircraft. Aerospace engineers must integrate these new technologies within the context of a pilot's cognitive capabilities and vulnerabilities when proposing new designs. It is

not within the scope of this discussion to investigate every complex issue and detail within the study of human factors. But, the contextual groundwork has been laid out up to this point to help the reader better understand the complexity of the man-machine relationship in aviation.

The civilian aviation industry has welcomed human engineering technology to their cockpits. Airlines are now turning their attention to other, more subtle human factors such as cockpit organization, crew interaction, fitness for duty (fatigue, health), judgment, sensory illusions, distraction, and complacency induced by reliability of equipment[59]. It is within these areas of interest that human factors scientists project the most opportunities to reducing pilot errors in the near future. As technology advances, opportunities for reducing overall workload levels and increasing situational awareness for the civilian pilots and aircrew can be primary objectives of the design engineers and human factors scientists. Airline companies also see the need to provide their pilots with the latest information technologies and automation measures to ensure safe flight. This is not to portray that the military does not desire to improve performance and safety. The fact is the USAF prioritizes their research efforts and resources within the context of tight budget constraints to develop combat aircraft with superior combat capabilities. It makes sense that the USAF tends to lean forward and give priority to new combat capabilities, ensuring future combat pilots have the latest and greatest weapons available to them at the start of the next conflict. But, does it make sense to add these new capabilities and tasks to current fighter pilot workloads without analyzing the second and third order effects on mental workloads and task saturation? The outcome of such a strategy could well result in pilots becoming even more prone to human errors and poor performance when flying future aircraft with a design emphasis on information superiority.

Airline companies have focused time and resources to research and field information technologies and automation toward the most critical man-machine interface in aviation, the pilot's checklist, in the hope of increasing pilot performance and safety. This is partly due to an authoritative intervention on the part of a National Transportation Safety Board (NTSB) Safety

Study identifying a need for the airline industry to increase human factors awareness related to checklist usage and design. The study cited the improper use or the failure to use a checklist when required as a causal or contributing factor in multiple aircraft accidents between 1978 and 1990[60]. Consequently, the airline industry has been installing and upgrading all of their aircraft with electronic checklists on multi-purpose displays in the last five years. A few aviation companies have even displayed standard instrument departure and approach procedures on electronic displays to capture the same advantages reaped from using electronic checklists. Are military aircraft so fundamentally different that these same goals are not valid? Absolutely not.

USAF combat aircraft and their respective missions invoke greater demands on pilots' cognitive and physical skills than airline aircraft and missions. Current fighter aircraft require large amounts of a fighter pilot's attention resources due to challenging tasks, compartmentalized cockpit design, increasingly complex weapons and sensor suites, digitization, and multi-role missions with high stress levels. Does it not meet the common sense test to say fighter pilots require the same, if not more, of these capabilities for the same reasons? Today's military aircraft use the same checklist technology as the Wright Brothers used 97 years ago, with the addition of plastic covers to prevent excessive wear and tear. The Air Force has made no conscious human factors effort to identify possible human factors and checklist problems.

The job of the checklist is to provide critical knowledge and guidance to the pilot about the aircraft and the specific actions needed to accomplish the task at hand. Checklists are used by pilots to properly configure an aircraft for safe flight and they provide a sequential framework to meet cockpit operational requirements. This provides a foundation of standardization and cockpit safety. Checklists are intended to act as an aid to the memory and helps to ensure that critical items necessary for the safe operation of aircraft are not overlooked or forgotten[61]. Safety reports continuously reveal a very delicate and integral relationship between a pilot and his checklist. Any pilot deviations from the correct operating procedures often result in fatal crashes. A random review of over 300 accident reports provided by pilots to the Aviation Safety Reporting

System (ASRS) operated by National Air and Space Administration (NASA) for the FAA also suggested more emphasis should be placed on the use of checklists. The review provided trend information invaluable to identifying a significant amount of checklists errors as causal or contributing factors to accidents. The review showed the following results[62]:

(1)   Crew failed to use the checklist.

(2)   Crew overlooked item(s) on the checklist.

(3)   Crew failed to verify settings visually.

(4)   Checklist flow was interrupted by outside sources.

(5)   Operator's or aircraft manufacturer's checklist contained error(s) or was incomplete.

Obviously, the results show if aircrew are not committed to strict adherence to checklists, the overall checklist objectives of supporting human performance and standardization are jeopardized. The FAA study best sums up the checklist, a man-machine interface, by the following passage:

> In addition to assisting the crew to configure and operate the aircraft properly, the checklist provides a method and a sequence for verifying the overall system operation. It is an important aid in helping the crew to remain focused to the task at hand by eliminating guesswork that often accompanies periods when crew attention is divided especially during periods of stress or fatigue. The checklist is an important and necessary backup for the pilot and crew[63].

As this research has highlighted the complexities within aviation, the NTSB and Aviation Safety Reporting System reports suggest other human factors issues, along with checklist discipline, are responsible for checklist error.   This list of cognitive vulnerabilities includes the following; fatigue, pilot reliance on short-term memory, cockpit interruption, distraction, and complacency that may affect pilot performance and have the potential to cause checklist error.   These factors are linked and their effects can accumulate to unacceptable levels, if not recognized. A pilot's situational awareness, in these situations, will become low and pilots will become task saturated and prone to error.   During a period of low performance, as described above, judgment can become impaired and a pilot's desire to get back "ahead of the jet" increases the risk that short-cutting procedures, e.g., checklists, may occur[64].

The term fatigue is usually defined in terms of physical weariness or failure. Within the context of this discussion, fatigue and stress are interchangeable terms and the thrust of the research is focused on the mental aspect of fatigue. A fatigued, or task saturated individual tends to prioritize tasks according to their perceived importance with the possibility of not finishing all tasks due to availability of time. Depending on the pilot's cognitive ability and the situation, new tasks may be refused or attention to current tasks will be reduced to accommodate new tasks. Under these conditions, the successful completion of checklist procedures becomes significantly reduced.

The FAA also highlighted interruptions and distractions as primary contributors to pilot error. The civilian flying community has organized flying operations into phases in an attempt to identify periods of vulnerability to external factors during normal procedures. NTSB reports showed a tendency for pilots to be most vulnerable to interruptions and distractions during ground operations before takeoff. This could also be a function that ground operations constitute the largest percentage of normal checklist procedures compared to other phases. The events that take place during the pre-departure phase often do not occur in a logical sequence and are susceptible to external factors, requiring aircrew to possess a greater sense of situational awareness, attention resources, and teamwork to overcome the incoming interruptions and distractions. The FAA recommended that once checklist flow has been interrupted or an item placed on hold, the checklist should not be stowed. They provided various techniques on how to position the checklist in a conspicuous spot, or kept in hand, as methods to remember that a certain checklist procedure is not complete[65]. Memory recal will be challenged after interruptions and distractions have occurred. Again, military and civilian ground operations are alike, but fighter pilots possess the added burden of no one reminding them to "clean up" checklist items after the distraction has occurred. Obviously, the effects of interruptions and distractions can be greatly magnified during abnormal and emergency checklist procedures.

Limitations of short-term, or working memory, is another vulnerability that can inhibit reciting critical action items from a checklist. Interference, defined as incoming noise or verbal communications and labeled as interruptions or distractions, is the principal cause of loss of information from short-term memory. The capacity and duration of individual information items stored is quite limited when compared with other cognitive skills of the human brain. Information stored in short-term memory either is forgotten or is replaced by new information in a remarkably short period of time. As imagined, stress and fatigue degrade the brain's ability to maintain information in the short-term memory storage areas. It was evident to the FAA and airline companies that a situation was developing that pilots were requiring assistance with the complexities of newer aircraft. Electronic checklists were seen as a solution to this human factors problem and fielded to major airlines.

The design of electronic checklists will not guarantee error-free flying operations. However, it is hoped this application of technology, as proven in the civilian community, can help military pilots manage workloads and situational awareness better, resulting in lower occurrences of human error within the Air Force community. The checklist can be an effective tool and, under certain conditions, can reduce pilot workload[66]. As pointed out earlier, keeping pilots out of heavy workload situations is necessary for achieving optimum performance during normal operations, as well as abnormal or emergency situations. Location is equally important for electronic checklists. Checklists easily found in the cockpit and readable under all lighting conditions are more resistant to error and will enable aircrew to managing cockpit information and workload better. Checklists stored in obscure map cases or on a kneeboard are difficult to access and pose a distraction to primary flying duties when trying to access appropriate procedures. The pilots' attention is often diverted from other tasks when performing a checklist. In order to minimize a head down posture and diversion time while accessing and executing checklist procedures, the checklist should be located in an ergonomically sound location to avoid interruption, distraction, and spatial disorientation. Computer automation and information

technology have aided in managing sophisticated aircraft systems, while the emergence of Head-Up Displays (HUD) allows pilots to view vital aircraft information without having to go head-down in the cockpit. This allows situational awareness to remain high regarding the outside environment and aircraft performance. Multi-purpose displays, made with cathode ray tube technology, aid in managing the vast amounts of data available from aircraft computers. They have the capability to display information at one central location, or in any order or location as the pilot dictates. Another consideration that is unique to fighter aircraft is the bubble canopy. The pilot has the capability to view 360 degrees around the aircraft and below the horizontal axis of the aircraft. With this great vantage point are some drawbacks. The bubble canopy lends the pilot susceptible to spatial disorientation while flying at night or in inclement weather. Spatial disorientation for the aircrew becomes more aggravated when the individual puts his head down in the cockpit for a switch actuation or retrieval of a checklist. It is essential that all important information should be displayed and formatted in a way that offers aircrew the most automatic and user-friendly presentation, enhancing their situational awareness and assisting them quickly in high workload or stressful situations.

Technology has allowed information to be displayed on mult-purpose displays with a desire to extract as much detailed information from the machine as is capable of presenting to the pilot. The positive side of this capability is the electronic displays and digits provide excellent data in excruciating detail, but the problem is they do not present rate of data change very well to the pilot in current formats.

Comparison Table 5.1 and 5.2 will show the differences between current USAF paper checklists and current electronic checklists being made by civilian aviation manufacturers for airline companies. The lists of advantages and disadvantages show the human factors issues involved with checklist design.

Paper Checklist

Advantages	Disadvantage
1. Easy to stow	1. Easily damaged or worn
2. Inexpensive to produce	2. Easy to misplace
3. Inexpensive to update	3. Easy to remove from aircraft
	4. May be difficult to read if type size or fonts are not adequate
	5. May be difficult to read under low ambient light during night flying – night vision will be compromised if bright light is used to see checklist
	6. No memory or recall feature
	7. No automatic means of noting progress if interrupted or distracted
	8. Promotes heads down body position to read
	9. Hand held-not conducive to flying

Table 5.1

Electronic Checklist

Advantages	Disadvantages
1. Is stationary in the aircraft	1. Must share time or displace other needed displays, e.g., Radar, navigation
2. Cannot remove or lose it	2. May be hard to locate a list or return to a certain point
3. Some equipped with sensors that verify checklist items completed	3. Cost and expense of installation
4. Retains legibility	4. Expense of updating checklists through software changes
5. Ability to see checklist in all scenarios	
6. Provides a systematic recall if items are deferred	5. Need for paper backup due to possibility of total display or electrical failure
7. Minimizes spatial disorientation with limited body and head movements	
8. Does not require pilot to hold checklist	
9. Ability to store vast amounts of information that is easily accessible	
10. Centralizes standardization responsibilities	
11. Quickly accessible-not so reliant on memory	
12. Facilitates an organized cockpit and workload management	

Table 5.2

Chapter VI
Conclusions and Recommendations

The cognitive powers of the human brain are being pushed to the very limits in today's fighter aircraft. The limitations and capabilities of future aircraft will most likely lie within the spectrum of human factors and the design of man-machine interfaces instead of the physical prowess of an aircraft's aerodynamics. The combat pilot of the future will be required to access and analyze greater amounts of information. The question is whether the pilot will be able to absorb the critical information in a timely manner and execute decisions incorporating this information toward successful conclusion?

Situational awareness has become the most important factor in the complex decision-making process which determines if a fighter pilot is successful or not. Mental workloads have reached incredible heights in the last decade, leading pilots to becoming cognitively saturated and ultimately losing situational awareness. Once a pilot finds himself in this situation, the likelihood of him making poor decisions and cockpit errors significantly increases.

Cognitive psychologists have led the way in trying to find effective methods of predicting and reducing dangerous errors by way of better understanding the human brain's mental processes. Their aim is to identify and reduce pilots exposure to situations vulnerable to error. Human factors scientists are researching information processing, and how humans interact with machines such as aircraft, ships, and computers themselves. A principal feature of the information process is the relationship between stimuli and responses and the series of sequential stages or mental operations which occur between those two events. The researchers have identified the importance that pattern recognition, memory, and experiences interact within the process. Understanding the information process is a crucial part of the man-machine interface.

Another important aspect of predicting vulnerabilities to error includes workload management and the integration of automation to flying operations. Automation is theorized to help eliminate human error and enable pilots to handle increased workloads imposed by mission

requirements. Automation helps or assists pilots make better assessments of their environment and avoid task saturation. In the past, as technology provided solutions, the cockpit became more complex and new problems were created. The cumulative effects of these technologies, which were intended to increase situational awareness and lethality, are often responsible for the loss of situational awareness due to task saturation. New cockpits require pilots to possess skills to monitor and set a myriad of devices. The mind however, is not especially good at these specific tasks, this leads to detection failures and the inability to diagnose failures or errors. The NTSB data reinforces this perspective by exposing the fact that pilots occasionally fail to respond appropriately to emergencies. The other side of the workload/performance relationship suggests individuals under a very low workload also experience low situational awareness and are prone to complacency and boredom. Human factors engineers have acknowledged the potential downfalls of automation and the loss of pilot control over their environment.

Pilots in a digital cockpit exist in an information-rich environment. The challenge for designers is to organize and present multiple sources of information in a meaningful and accessible manner. During abnormal or emergency situations, pilots do not have the time to select critical information from unimportant information. The goal is to provide the necessary information in a timely and comprehensible manner while maintaining pilot workload within an acceptable range[67]. Either side of the workload/performance relationship demonstrates workload of an individual is a very important determinant in causing human error. Trying to balance the opposing effects of task saturation and complacency demonstrates the importance of optimizing an individual's workload and avoiding vulnerability to human error.

The NTSB, FAA, and ASRS identified this dubious relationship and pressed for the injection of innovative technologies into cockpits to optimize workloads to improve overall pilot performance. The results of these organizations'studies highlighted the need for the airline industry to increase human factors awareness, across the board, particularly focusing on checklist design and usage. The aviation community decided it was time to allocate solutions to the

cognitive aspect of the equation. Fueled by these external influences and an introspective mindset, airline companies began focusing time and resources to research and create information technologies and automation toward checklists, in the hope of increasing pilot performance and safety. The requirement for a more robust human factors awareness in the military is equally important and can be verified by looking at recent United States Navy mishap database.

Fifty-three percent of the Navy's mishaps that occurred between 1996 and September 2000 were categorized as having causal factors directly related to human factors issues. Physical errors committed by pilots constituted thirty-nine percent of the mishaps during that same time period[68]. These numbers point to an overwhelming trend of pilot vulnerability to error. See Appendix A for a more comprehensive breakdown of Navy mishaps and accidents between 1996 and 2000. The USAF's Safety Center would not release similar mishap data to this research effort due to different regulations concerning the integrity of investigative confidentiality. But, similar accident trends in the Air Force are projected to resemble the Navy's mishap data. The fact is there would be a significant increase in raw mishap data due to the Air Forces' number of airframes and sortie rates.

So far, the USAF continues to use hand carried paper checklists and is missing a golden opportunity to follow suit and address this issue. Today's checklist accessibility and institutional techniques to overcome current limitations in fighter cockpits is flawed. There exists a requirement to create and install new information technologies into combat aircraft to solve this problem just as the civilian sector has done. This critique focuses at both the mental and physical aspects of the man-machine interface, though a large portion of the research has focused on cognitive complexities of the problem. As aircraft have become more complex because of capabilities and flexibility requirements, the pilot's operating procedures have become more extensive and complex. A pilot's requirement to recite highly complex procedures, without the assistance of a memory jogger during stressful situations encountered in flying, ignores the basic principles of human cognitive performance and its' associated vulnerabilities. Similarly, the

longer the procedure has become to configure the aircraft or rectify the emergency, the more vulnerable the pilot is to task saturation and distraction before the checklist procedure is completed. It would be simpler to address the mental and physical characteristics in isolation. But, the mental and physical relationship would be unnatural and useless in such an isolated analysis. The physical tasks and requirements of the cockpit must be integrated with mind's cognitive tasks and requirements to fully understand the dynamics of this man-machine interface and the role of the checklist. There is little doubt training can improve pilot performance. But, not all of the answers lay solely within the cognitive side of the argument. Technology and automation must be leveraged, whenever possible, in an attempt to address and assist cognitive vulnerabilities.

The physical aspects of the issue are just as important and need to be researched and tested in conjunction with mental workloads before any solutions are finalized. The physical characteristics of the single-seat aircraft present some unique challenges to aircraft designers and fighter pilots when discussing checklist usage and design. Experience and research highlight the lack of available space in fighter cockpits as a major problem of storing and accessing paper checklists. This lack of real estate results in kneeboards becoming saturated with mission materials or checklists being stored in an obscure corner of the cockpit with no reasonable chance of becoming readily accessible when needed. Obviously, as highlighted earlier, the lack of another crewmate helping confirm checklist adherence and completion results in a higher chance of pilots committing checklist errors and becoming task saturated with other cockpit duties. Current paper checklists are not optimized to effectively manage high information rates, volumes of information, and excessive workload requirements during certain phases of flying operations in today's combat aircraft. The airline industry adjusted to these new requirements. It is now time for the military to step up to the task. In relationship to a pilot's physical position in the cockpit and required flying duties, current checklist usage and storage techniques are unsound and need to be addressed to reduce the pilot's vulnerability to spatial disorientation. Immediate access and

the ability to retrieve the appropriate actions from the checklist during an emergency, as well as during normal operations, without compromising aircraft control are valid safety requirements.

Little to no USAF research has been accomplished in studying the impact of installing electronic checklists on multi-purpose displays and assessing it's contribution to alleviating pilot error, complacency, distractions, task saturation, spatial disorientation, and increasing situational awareness. The USAF's lack of interest in this effort can possibly be interpreted and summarized with the following conclusions; human factors issues studied in the civilian flying community do not transfer over to military flying operations, weapons capabilities take priority over cockpit "luxuries", and information technologies are cost prohibitive.

In response to these conclusions, the facts are cognitive capabilities and vulnerabilities of the mind are universal. The cognitive characteristics of civilian pilots are the same as military pilots and are valid for either civilian or combat aircraft. A strong argument can be made that the missions of fighter aircraft require a more substantial ergonomic effort to alleviate task saturation, mental workload and physical space issues.

The second conclusion of concentrating on weapon systems is a necessity in the warfighting profession. But the mistake must not be made to ignore the human element of this complex man-machine interface. The overall performance of a weapon system, such as the aircraft, is only as good as the weakest subsystem. The USAF needs to reevaluate the conditions and environment of the modern fighter cockpit.

The last conclusion expressing concern over the cost of integrating information technologies into combat aircraft might have been valid ten years ago. Phenomenal increases in information and data storage capabilities in the last five years has put a whole new perspective on what is considered feasible, acceptable and suitable in a cost-benefits analysis. Depending on the sophistication of the initiative, it would be a simple and inexpensive task to incorporate a word file format into a software package and present the checklist in an electronic format on multi-purpose display. The software format would provide an unlimited amount of data expansion

capability for further requirements such as displaying departure and approach procedures. Just as the civilian community identified, military accident data show substantial numbers of military aircraft fall victim to pilot error each year. How many mishaps could be avoided by installing electronic checklists into the cockpit?

The fundamental conclusion resulting from this research is electronic checklists and data-based information banks can optimize pilot workload, situation awareness, and overall air combat performance by taking advantage of new information storage capabilities. The ultimate goal should be to integrate this information into the "glass cockpit" seamlessly without increasing pilot workload while reducing pilot error. Vital to the success of this endeavor is the ability to present this critical information in an intuitive and readily understood format.

The first recommendation from the research is the USAF should accept the fundamental human factors insights and conclusions of the aviation comunity concerning man-machine interfaces. If properly accepted, USAF researchers will find it necessary to investigate the current acceptable procedures and techniques of checklist usage, or lack there of, within the fighter community. The assessment from this inquiry is projected to require improvements be made in checklist design and usage. USAF human factors experts will reanalyze mental workloads and the physical layout of the cockpit to ensure current ergonomic issues are being addressed.

Further recommendations offer insight into possible electronic checklist formats with varying capabilities and required items of such an upgrade. The baseline requirements recommended for electronic checklist design are; compatibility with current multi-purpose displays, ability to show all required checklist information to include notes, cautions, and warnings, and lastly the easy accessibility and flexibility through current data transfer modules to facilitate making changes and adding supplements to checklist procedures to ensure checklist correctness by authorized standardization personnel. As alluded to earlier, the low-cost version of an electronic checklist can be as simple as a word-file format that would be navigated to required procedures in the checklist by push buttons on the side of current multi-purpose displays.

42

A higher quality format could include sensors to critical systems within the jet to include: engines, hydraulics, fuel tanks, and electrical system. The sensors would alert the electronic checklist of specific malfunctions or failures and automatically bring up the appropriate critical action checklist procedure that the pilot would be required to complete. A possible top-of-the-line format would incorporate the same idea of having sensors monitoring critical systems required for safe flight, but would delegate control to automated actions completed by the jet once a malfunction or failure was identified by the sensors.

The aim of future display systems should be to remove some, if not all, of the workload and provide pilots with both constant updating of critical information and mission-specific data for the varying phases of an operation. At the same time, the display system should ensure that any display of urgent information is immediately perceived and acknowledged by the pilot. Electronic checklists do not represent a revolutionary leap in technology or fighter capability, but rather an enhancement to current ways of performing required cockpit duties.

Automating the fighter pilot's checklist is an inexpensive and simple solution to fight task saturation, susceptibility to spatial disorientation and overall mental errors. Thus, the advantages and effects gained by spending a minimal amount of money to add a simple word file to a multi-purpose display could be instrumental in helping to prevent aircraft mishaps, accidents, and deaths. Although this capability is not directly related to combat capabilities, implementation of an electronic checklist is an effective and efficient way to improve pilot performance and inevitably protect warriors and combat aircraft from preventable accidents. A force multiplier by any definition!

Appendix A

Navy Safety Center Aviation Database
01 Jan 96 – 29 Aug 00

Human Factor Category	# of Mishaps	% of Total Mishaps
Checklist Error	44	14%
Task Saturation	45	15%
Spatial Disorientation	31	10%
Loss of Situational Awareness	36	12%
Fatigue	2	1%
Complacency	5	2%
Total Human Factors	163	54%

Other Categories of Mishaps		
Physical Pilot Error	86	28%
Training	17	5%
Rules Violation	3	1%
Maintenance Error	5	2%
Material Failure	25	8%
No Fault	5	2%
Total of Other Categories	141	46%

Mental and Physical Errors by Pilots	**249**	**82%**

* Data includes all Navy and Marine Aviation to include Helocopters, Fighters, and Transports – 304 mishaps total.

Terms and Definitions

Abnormal. Used to describe a situation, procedure, or checklist in reference to a non-routine operation in which certain procedures or actions must be taken to maintain an acceptable level of situational awareness, systems integrity or airworthiness.

Caution. An instruction concerning a hazard that if ignored could result in damage to an aircraft component or system – which would make a continued safe flight improbable.

Checklist. An abbreviated publication detailing aircraft and weapons pre-flight items, normal procedures, emergency procedures, special procedures, and reference data. The checklist contains itemized procedures without the detail that the technical manuals provide. Used as a visual or oral aid that enables the user to enhance short-term human memory.

Crew Resource Management (CRM). Formally known as Cockpit Resource Management, refers to the effective use of all available resources; human Resources, hardware, and information.

Decision Making. The process of selecting a course of action from available options, based upon whatever information is available at the time.

Ergonomics. See Human Factors.

Emergency. When emergency is used to describe a procedure or checklist, it refers to a non-routine operation in which certain procedures or actions must be taken to protect the crew and the passengers, or the aircraft, from a serious hazard or potential hazard.

Glass Cockpit. Aircraft cockpits that have integrated new technology displays, gauges, digitization, Heads-Up-Display (HUD), and other information sharing technologies.

Human Factors. A multi-disciplinary field developed to optimizing human performance and reducing human error. It incorporates the methods and principles of the behavioral and social sciences, engineering, and physiology. Human factors is the applied science which studies people working together in concert with machines. Human factors embraces variables that influence team or crew performance.

Immediate Action. An action that must be taken in response to a non-routine event so quickly that reference to a checklist is not practical because of a potential loss of aircraft control, incapacitation of a crewmember, damage to or loss of an aircraft component or system, which would make continued safe flight improbable.

Leans. A type of spatial disorientation that distorts a pilot's senses of position and attitude in relation to the surrounding environment.

Mishap. An aircraft accident or incident in which the aircraft sustains damage or the aircrew is injured.

Multi-purpose Display (MPD). A monochromatic cathode ray tube/television that is capable of displaying system data, sensor video, and weapon information. The MPDs have 20 peripheral pushbuttons by which the pilot can control weapon systems, sensors, and data to be displayed. Legends are positioned adjacent to

each pushbutton to advise the crew of modes and options selectable for operation of the onboard radar, sensors, navigation, and weapon systems.

Normal Checklist. A checklist comprised of all of the phase checklists used sequentially in routine flight operations.

Situational Awareness (SA). The overall integration of information received through a pilot's sensory channels over a period of time. The information is processed to form mental picture of the pilot's aircraft and its relationship with the surrounding environment, comprehending the significance of all events and relationships. The highest level of SA is the ability to project the future actions of the elements in the environment.

Spatial Disorientation. Loss of proper bearings; state of mental confusion as to position, location, attitude, or movement relative to the position of earth.

Technical Manual. An United States Air Force manual that contains all encompassing information for safe and efficient operation of aircraft.

Warning. An instruction about a hazard that, if ignored, could result in injury, loss of aircraft control, or loss of life.

Weapon System. A combination of the specific aircraft, avionics, aircrew, flying gear (including pilot's checklist), training, and ordinance.

Notes

[1] David C. Nagel, "Human Error in Aviation Operations," <u>Human Factors in Aviation</u>, (San Diego: Academic Press Inc., 1988), pg 263-266; The 80% figure comes from the combination of air carrier crew error (approx. 70%) and general aviation's rate of 9 out of 10 (90%) accidents are attributable to human causes.

[2] Mica R. Endsley, "A Methodology for the Objective Measurement of Pilot Situational Awareness", <u>Situational Awareness in Aerospace Operations</u>, (Denmark: AGARD conference proceedings No. 478) pg 2.

[3] Ibid, pg 2.

[4] Ibid, pg 4.

[5] K. Gerbert and R. Kemmler, "The Causes of Causes: Determinants and Background Variables of Human Factor Incidents and Accidents," <u>Ergonomics</u>, Vol. 29, No. 11, pg 1439-1453.

[6] Larry Bolman, "Aviation Accidents and the "Theory of the Situation," Proceedings of NASA/Industry Workshop held at San Francisco, California June 26-28, 1980.

[7] K. Gerbert and R. Kemmler, "The Causes of Causes: Determinants and Background Variables of Human Factor Incidents and Accidents," <u>Ergonomics</u>, Vol. 29, No. 11, pg 1439-1453.

[8] Eleana S. Edens, "Individual Differences Underlying Pilot Cockpit Error," Dissertation for the degree of Doctor of Philosophy, (George Mason University: FAA, 1991), pg 116-117.

[9] Ibid, pg 439.

[10] John Lauber, Forward in <u>Cockpit Resource Management</u>, eds. Wiener, E., L., Kanki, S., Helmreich, R. (San Diego: Academic Press Inc., 1993).

[11] James Reason, <u>Human Error</u>, (Cambridge: Cambridge University Press, 1990), pg 1.

[12] Ibid, pg 5-6.

[13] Ibid, pg 7.

[14] Ibid, pg 6.

[15] Ibid, pg 8-9.

[16] Ibid, pg 11.

Notes

[17] Ibid, pg. 11.

[18] Ibid, pg. 11.

[19] Ibid, pg 12.

[20] Ibid, pg 97.

[21] Cristopher D. Wickens and John M. Flach, "Information Processing," <u>Human Factors in Aviation</u>, (San Diego: Academic Press Inc., 1988), pg 112; Figure slightly modified by author, added category called "experience" to include pattern recognition and long-term memory.

[22] Ibid, pg 113

[23] Gary Klien, <u>Sources of Power</u>, (Boston: Massachusetts Institute of Technology, 1999) pg 1.

[24] Ibid, pg 3.

[25] Ibid pg 17.

[26] Ibid pg 31-44.

[27] Ibid, pg 197-213.

[28] Ibid, pg 177.

[29] Cristopher D. Wickens and John M. Flach, "Information Processing," <u>Human Factors in Aviation</u>, (San Diego: Academic Press Inc., 1988), pg 126

[30] B. P. Goettl, "The Interfering Effects of Processing Code on Visual Memory", Proceedings of the 29th Annual Meeting of the Human Factors Society, (Santa Monica, CA, 1985)

[31] Mica R. Endsley, "A Methodology for the Objective Measurement of Pilot Situational Awareness", <u>Situational Awareness in Aerospace Operations</u>, (Denmark: AGARD conference proceedings No. 478) pg 4.

[32] G. A. Miller, "The Magical Number Seven Plus or Minus Two: Some Limits on Our Capacity for Processing Information", <u>Psychology Review</u>, Vol 63, pg 81-97 (1956)

Notes

[33] Mica, R. Endsley, "A Methodology for the Objective Measurement of Pilot Situational Awareness", <u>Situational Awareness in Aerospace Operations</u>, (Denmark: AGARD conference proceedings No. 478) pg 1-3.

[34] Cristopher D. Wickens and John M. Flach, "Information Processing," <u>Human Factors in Aviation</u>, (San Diego: Academic Press Inc., 1988), pg 113.

[35] Gary Klien, <u>Sources of Power</u>, (Boston: Massachusetts Institute of Technology, 1999) pg 45-62.

[36] Ibid, pg 52-53.

[37] Ibid pg 16-17.

[38] Gary Matthes, "Mission Planning and Proper Design: The Long Range Connection," <u>The Man-Machine Interface in Tactical Aircraft Design and Combat Automation</u>, (Stuttgart: AGARD conference proceedings No. 425, 1987), pg 3-2.

[39] James R. Beniger, <u>The Control Revolution</u>, (Cambridge: Harvard University Press, 1986) pg 7-8.

[40] Ibid, pg 8.

[41] Earl L. Wiener, "Cockpit Automation," <u>Human Factors in Aviation</u>, (San Diego: Academic Press Inc., 1988), pg 444.

[42] C. V. Glines, "Human Factors and the Glass Cockpit," <u>Airline Pilot</u>, October 1990, pg 21.

[43] Barry H. Kantowitz and Patricia A. Casper, "Human Workload in Aviation," <u>Human Factors in Aviation</u>, (San Diego: Academic Press Inc., 1988), pg 160-161.

[44] Earl L. Wiener, "Beyond the Sterile Cockpit," <u>Human Factors</u>, Vol. 27, pg 75-90., 1985.

[45] Earl L. Wiener and R. E. Curry, <u>Flight Deck Automation: Promises and Problems</u>, (San Diego: Academic Press Inc., 1980) pg 995-1001.

[46] Kevin Kelly, <u>Out of Control</u>, (Reading, Massachusetts: Addison-Wesely, 1994) pg 330.

[47] Barry H. Kantowitz and Patricia A. Casper, "Human Workload in Aviation," <u>Human Factors in Aviation</u>, (San Diego: Academic Press Inc., 1988), pg 157-159.

Notes

[48] Earl L. Wiener, "Cockpit Automation," <u>Human Factors in Aviation</u>, (San Diego: Academic Press Inc., 1988), pg 437.

[49] Richard S. Jensen, <u>Aeronautical Decision Making-Cockpit Resource Management</u>, (Ohio State University Research Foundation, Aviation Psychology Laboratory, January 1989) pg 51.

[50] Ibid, pg 51-52.

[51] Barry H. Kantowitz and Patricia A. Casper, "Human Workload in Aviation," <u>Human Factors in Aviation</u>, (San Diego: Academic Press Inc., 1988), pg 171-178.

[52] Ibid, pg 177.

[53] S. L. Berg and Thomas B. Sheridan, "Measuring Workload differences between short-term memory and long-term memory Scenarios in a Simulated Flight Environment," Proceedings of the 20th Annual Conference on Manual Control, (Moffett Field, CA: NASA-Ames Research Center, 1984), pg 397-416.

[54] Barry H. Kantowitz and Patricia A. Casper, "Human Workload in Aviation," <u>Human Factors in Aviation</u>, (San Diego: Academic Press Inc., 1988), pg 177.

[55] Key Dismukes, "Cockpit Interruptions and Distractions," <u>Flying Safety Magazine</u>, (Air Force Safety Center, Kirtland AFB, NM, June 1999) pg 19.

[56] G. Johannsen and W. B. Rouse, "Studies of Planning Behavior of Aircraft Pilots in Normal, Abnormal, and Emergency Situations," <u>IEEE Transactions on Systems, Man, and Cybernetics</u>, Institute of Electrical and Electronic Engineers, Inc. Service Center, 1983, pg 267-278.

[57] Elwyn Edwards, "Introductory Overview," <u>Human Factors in Aviation</u>, (San Diego: Academic Press Inc., 1988), pg 5.

[58] Ibid, pg 5.

[59] Jerome Lederer, Forward in <u>Human Factors in Aviation</u>, (San Diego: Academic Press Inc., 1988), pg XV.

[60] NTSB Safety Study, "A Review of Flightcrew-involved, Major Accidents of U.S. Air Carriers, 1978 through 1990," (Sringfield, VA: National Technical Information Service, 1994), Report Number NTSB/SS-94/01, pg 1-3.

[61] Federal Aviation Administration, "Human Performance Considerations in the Use and Design of Aircraft Checklist," (U.S. Dept of Transportation, 1995), pg 12.

Notes

[62] Federal Aviation Administration, "Human Performance Considerations in the Use and Design of Aircraft Checklist," (U.S. Dept of Transportation, 1995), pg 9.

[63] Ibid, pg 14.

[64] Ibid, pg 18.

[65] Ibid, pg 20.

[66] Ibid, pg 34.

[67] L. Harrison, J. Janowitz, and M. Castronuovo, "The Pilot-Vehicle Interface," Research for Federal Aviation Administration, (U.S. Department of Transportation, NJ, 1993) pg 120.

[68] Navy Safety Center Mishap Database, Investigation Recaps of Navy and Marine Mishaps from January 1996 to August 2000 with Safety Boards conclusions on Causal Factors. POC at Navy Safety Center was safety analyst Lt Joy Dean of USN, jdean@safetycenter.navy.mil.

Bibliography

Books

Beatty, D. <u>The Human Factor in Aircraft Accidents</u>. New York: Stein & Day, 1969.

Beniger, James R., <u>The Control Revolution</u>, Cambridge, MA: Harvard University Press, 1986.

Kantowitz, B. H. and Sorkin, R. D. <u>Human Factors: Understanding People-System Relationships</u>. New York: Wiley, 1983.

Kelly, Kevin, <u>Out of Control</u>, Reading, MA: Addison-Wesely, 1994.

Klien, Gary, <u>Sources of Power</u>, Boston, MA: Massachusetts Institute of Technology, 1999.

Nagel, D., <u>Human Factors in Aviation</u>, San Diego, CA: Academic Press Inc., 1988.

Reason, James, <u>Human Error</u>, Cambridge, MA: Cambridge University Press, 1990.

Wiener, E., S. Kanki, and R. Helmreich, <u>Cockpit Resource Management</u>, San Diego, CA: Academic Press Inc., 1993.

Wiener, E. and R. E. Curry, <u>Flight Deck Automation: Promises and Problems</u>, San Diego, CA: Academic Press Inc., 1980.

Publications

Air Force Instruction 11-403., <u>Aerospace Physiology Student Workbook</u>. USAF Publication, 1995.

Alkov, R. A. "Human Factors History of Cockpit Displays", in <u>Flying Safety</u>. Sep 1994.

Buckland, B. "Big Screen Cockpit Displays Enhance Pilot Capabilities", in <u>Defense Electronics</u>. May 1992.

Dismukes, K. "Cockpit Interruptions and Distractions: Effective Management Requires A Careful Balancing Act", in <u>Flying Safety</u>. Jun 1999.

Endsley, Mica, R., "A Methodology for the Objective Measurement of Pilot Situational Awareness." <u>AGARD: Situational Awareness in Aerospace Operations</u>, No. 478, pg 2.

Gerbert, K., and R. Kemmler, "The Causes of Causes: Determinants and Background Variables of Human Factor Incidents and Accidents." <u>Ergonomics</u>, Vol. 29, No. 11, pg 1439-1453.

Glines, C. V., "Human Factors and the Glass Cockpit." <u>Airline Pilot</u>, October 1990.

Matthes, Gary, "Mission Planning and Proper Design: The Long Range Connection," <u>AGARD: The Man-Machine Interface in Tactical Aircraft Design and Combat Automation</u>, No. 425, pg 3-2.

Miller, G. A., "The Magical Number Seven Plus or Minus Two: Some Limits On Our Capacity for Processing Information." <u>Psychology Review</u>, Vol. 63, 1956.

Phillips, E. H. "NASA Probes Pilot Awareness", in <u>Aviation Week & Space Technology</u>. 8 Apr 96.

Wiener, E., "Beyond the Sterile Cockpit." <u>Human Factors</u>, Vol. 27, pg 75-90.

<u>Miscellaneous</u>

Berg, S. L., and T. B. Sheridan, "Measuring Workload Differences Between Short-Term Memory and Long-Term Memory Scenarios in a Simulated Flight Environment," Proceedings of the 20th Annual Conference on Manual Control, NASA-Ames Research Center, Moffett Field, CA, 1984, pg 397-416.

Bolman, L., "Aviation Accidents and the Theory of the Situation," Proceedings of the NASA/Industry Workshop, San Francisco, CA: Jun 26-28, 1980.

Edens, E., "Individual Differences Underlying Pilot Cockpit Error," Dissertation for the degree of Doctor of Philosophy, George Mason University, Printed by FAA, 1991.

Edwards, Elwyn, "Introductory Overview," <u>Human Factors in Aviation</u>, San Diego, CA: Academic Press Inc., 1988, pg 5.

Federal Aviation Administration, "Human Performance Considerations in the Use and Design of Aircraft Checklists," Washington D.C., 1995, pg 12.

Goettl, B. P., "The Interfering Effects of Processing Code on Visual Memory," Proceedings of the 29th Annual Meeting of the Human Factors Society, Santa Monica, CA, 1985.

Harrison, L., Janowitz, J., and M. Castronuovo, "The Pilot-Vehicle Interface," Research for Federal Aviation Administration, U.S. Department of Transportation, NJ, 1993, pg 120.

Jensen, Richard S., "Aeronautical Decision Making-Cockpit Resource Management," Ohio State University Research Foundation, Aviation Psychology Laboratory, January 1989.

Johannsen, G., and W. B. Rouse, "Studies of Planning Behavior of Aircraft Pilots in Normal, Abnormal, and Emergency Situations," <u>IEEE Transactions on Systems, Man, and Cybernetics</u>, Institute of Electrical and Electronic Engineers, Inc. Service Center, 1983, pg 267-278.

Kaempf, G. L., Klein, G. A. and Thordsen, M. L. "Applying Recognition-Primed Decision Making to Man-Machine Studies." Contract NAS2-13359. Moffett Field, CA: NASA-Ames Research Center, 1991.

Klein, G. "Sources of error in naturalistic decision making tasks", in Proceedings of the Human Factors and Ergonomics Society, 37th Annual Meeting, 1993.

Klinger, D. W., Andriole, S. J., Militello, L. G., Adelman, L., Klein, G., and Gomes, M. E. "Designing for performance: A cognitive systems engineering approach to modifying an AWACS human-computer interface." AL/CF-TR-1993-0093. Wright-Patterson AFB, OH: Department of the Air Force, Armstrong Laboratory, Air Force Materiel Command, 1993.

Lederer, Jerome, Forward in <u>Human Factors in Aviation</u>, San Diego, CA: Academic Press Inc., 1988, pg XV.

Miami University, Coral Gables, FL. Dept of Management Science. "Human Factors of Advanced Technology (Glass Cockpit) of Transport Aircraft." NASA, Washington D.C.: 1989.

National Transportation Safety Board, "A Review of Flightcrew-involved, Major Accidents of U.S. Air Carriers, 1978 through 1990," NTSB Safety Study, Springfield, VA: National Technical Information Service, Report Number NTSB/SS-94/01, 1994.

Navy Safety Center Mishap Database, Investigation Recaps of Navy and Marine Mishaps from January 1996 to August 2000 with Safety Boards conclusions on Causal Factors. POC at Navy Safety Center was safety analyst Lt Joy Dean of USN, jdean@safetycenter.navy.mil.

Wiener, E. L., "Human Factors of Advanced Technology ("glass cockpit") Transport Aircraft." NASA Report 177528. Moffett Field, CA: Ames Research Center, 1989.